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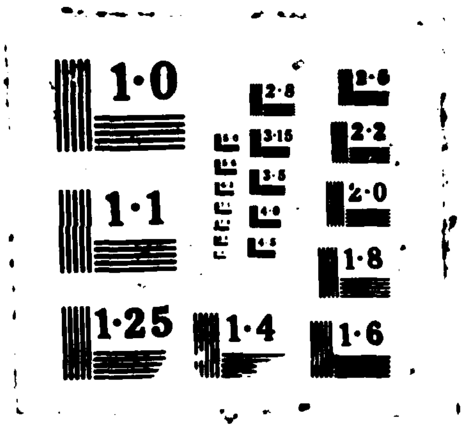
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TECHNICAL MEMORANDUM

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A TECHNIQUE FOR INVESTIGATION OF IGNITION PHENOMENA IN SMALL ARMS AMMUNITION

S.E. STEPHENSON

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A TECHNIQUE FOR INVESTIGATION OF IGNITION PHENOMENA IN SMALL ARMS AMMUNITION

S.E. Stephenson

ABSTRACT

Results are reported of experiments in which layers of propellant, sandwiched between layers of inert material in a modified 7.62 mm cartridge were ignited using standard Boxer percussion caps. These experiments yielded measurements of the penetration of the bed by the primer gases and hot particles and the corresponding effects on ignition. The technique is shown to be useful in characterising ignition and further experiments of a similar nature are proposed.

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1. INTRODUCTION

Predictable and reproducible performance from guns depends strongly on the process of initiation of the propellant and this is a function of the nature of the propellant/primer interface. Little is known at present about the initial conditions leading to propellant combustion despite the fact that such knowledge is essential as a boundary condition in interior ballistic modelling.

Impetus to explore this area was given by impending changes in the manufacture of small arms ammunition in Australia. Past experience in this country has been mainly with Berdan caps for 7.62 mm cartridges with two fireholes but there is now a requirement to manufacture 5.56 mm ammunition which utilises Boxer caps in cartridges with one firehole. This clearly represents a considerable change in the propellant/primer interface so a study of the effects was initiated. The initial part of this study, which is reported here, concerned the process of initiation itself with emphasis on penetration of the propellant bed by hot primer gases and particles and the propagation of pressure fronts through the granular propellant bed.

The work included experiments in which layers of propellant in an otherwise inert bed were ignited using standard primer caps (Boxer). The time from detection of the first pressure rise due to the passage of primer gases to the time at which self sustaining propellant combustion began was measured. This ignition delay is very sensitive to the position in the bed of the propellant layer and is used to define a penetration depth characteristic of the primer/propellant combination. Using two pressure sensors, measurements were made of the time of arrival of pressure pulses at two axially displaced positions in the bed, enabling the mean speed of propagation of pressure fronts through the granular bed to be determined. This speed is very much less than the speed with which intergranular stress waves move through the bed and indicates the possible importance of such stress waves in the ignition process. From the experiments which have been conducted, sufficient information has been obtained to identify those parameters most pertinent to the ignition process. In addition, a quantitative measure of the penetration of the granular bed by hot particles and gases from the primer is defined.

2. APPARATUS AND EXPERIMENTS

A cross section of the apparatus used in the experiments is shown in figure 1. A modified 7.62 mm cartridge case, shortened to 36 mm and held in place by a pair of collets, holds the percussion cap. The modified case fits into a chamber similar to a rifle chamber and is sealed at the base with a rubber O-ring and at the other end by a shear disc. When ignition occurs the shear disc ruptures and vents the chamber to atmosphere. The percussion cap is fired with a spring loaded mechanism screwed into the holder. This mechanism is described by Rye(ref.1). Pressure may be measured at two positions in the chamber located axially 12 mm apart but rotated about the axis relative to one another by 150°. For the pressure measurement nearer the primer it is necessary to drill a hole in the modified cartridge case at a distance of 24 mm from the base. The second pressure measurement is taken near the tip of the shortened case so no hole is required.

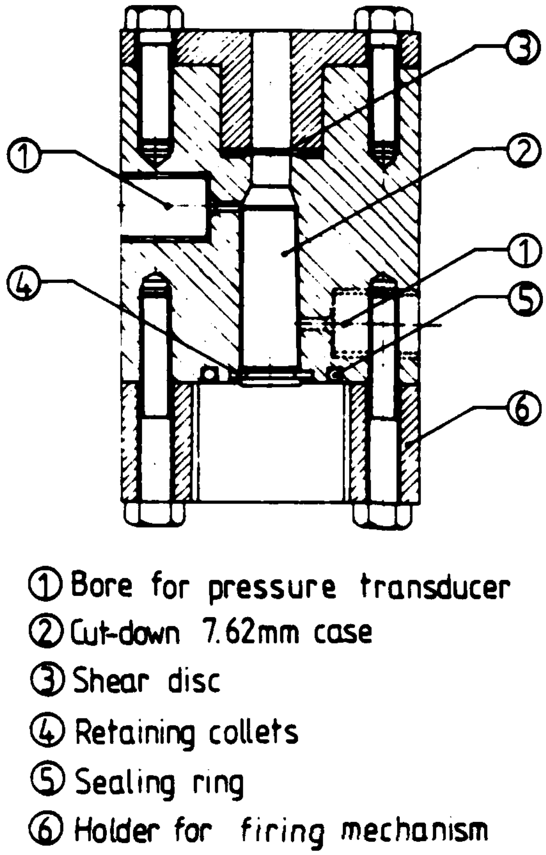

Figure 1. Cross section of 7.62 mm simulated cartridge

Pressures were measured with Kistler 6203 high pressure quartz transducers in conjunction with Kistler model 503D2 charge amplifiers. The signals from the charge amplifiers were recorded using a Philips PM3305 digital storage oscilloscope triggered by the action of the firing mechanism. The data was transferred to a Hewlett Packard HP-85 desktop computer and stored on magnetic tape cartridges for later processing.

In all experiments reported here a 0.355 g layer, 4 mm thick, of propellant AR2206 was sandwiched between layers of granular cellulose acetate at varying distances from the base of the cartridge. The inert material had the same geometrical form as AR2206. The manner in which the propellant layer and inert material were arranged in the modified chamber is shown schematically in figure 2. The propellant was positioned at distances of 1, 2, 3, 4 and 5 mm from the base of the modified cartridge and for each condition at least six firings were conducted. For all experiments reported here Omark Boxer CCI large rifle primer caps were used.

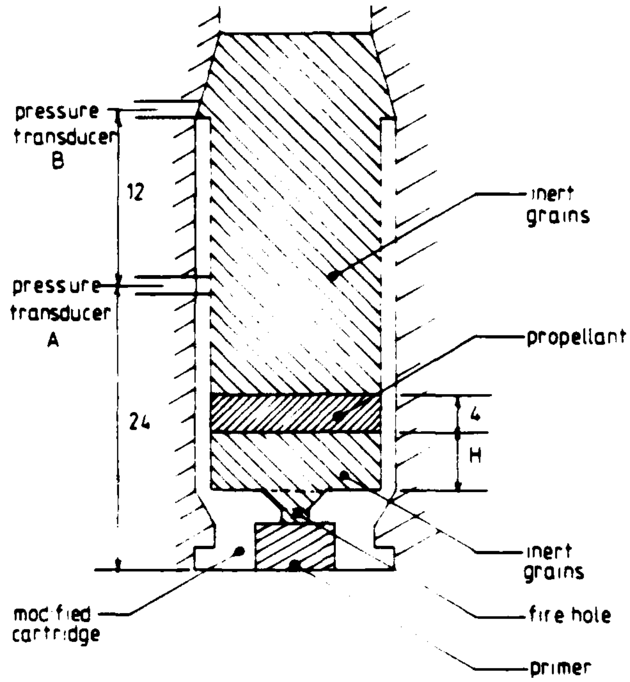

Figure 2. Arrangement of propellant and inert material in the modified cartridge

3. ANALYSIS OF EXPERIMENTAL RESULTS

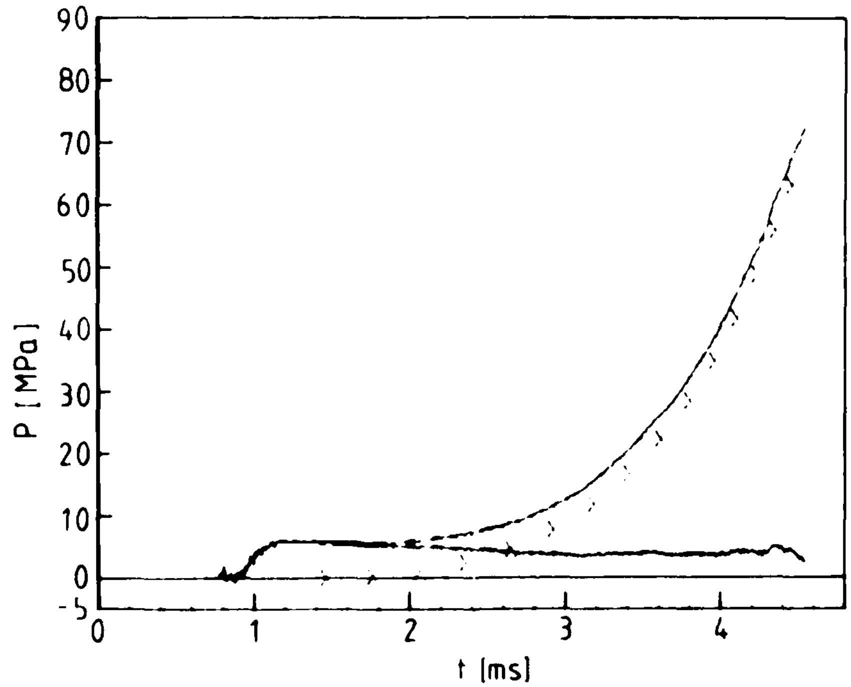

Figure 3. Typical pressure-time record showing separation of pressure into primary and secondary pressures. The upper curve is the total pressure, the lower curve, the primary pressure and X denotes the secondary pressure

Figure 3 shows a typical pressure-time trace recorded at the pressure port nearest the primer. For this experiment the layer of propellant was 1 mm from the base of the cartridge. The curve shows an initial rise in pressure due to the passage of primer gases, then a levelling off before the main pressure rise due to the self sustaining combustion of the propellant. One parameter of particular interest is the delay time from the initial detection of primer gases to the main rise in pressure due to combustion. This ignition delay was measured using the technique described by Stephenson(ref.2). The method of obtaining the time derivative of the pressure signal required by this technique was a modification of that previously used and is outlined in Appendix I. Figure 3 also shows the separation of the pressure signal into primary pressure due to the action of the primer and secondary pressure resulting from self-sustaining propellant combustion. The method of separation was also described previously(ref.2).

Measurements of ignition delay showed considerable variation even for experiments carried out under nominally identical experimental conditions. One factor considered in relation to this scatter was the possibility that the primers used may not have been of identical "strengths". As an indicator for the strength of the primer, the maximum slope of the initial pressure rise $(\dot{p}_1)_{max}$ was used. It was found that this slope was proportional to the local maximum in pressure due to the passage of primer gases $(p_1)_{max}$ but was more readily estimated, especially when the ignition delay was small and self-sustaining propellant combustion had commenced before the primer pressure reached its peak. Results indicated a loose negative correlation between deviations in log of ignition time and deviations in log of primary maximum pressure derivative (the correlation coefficient was 0.4). Ignition delay times t_{IG} were therefore normalised to t^*_{IG} for each experimental condition investigated using the relationship

$$t^*_{IG} = t_{IG}\,(\dot{p}_1)_{max}/\overline{(\dot{p}_1)_{max}}$$

where the overbar denotes an average over all tests under nominally identical conditions. Note that if the primary pressure maximum derivative had been constant in all tests under given conditions there would be no difference between t_{IG} and t^*_{IG}. The normalisation merely relates t_{IG} to the "strength" of the primer.

Since the spread in ignition delay times was of the same order of magnitude as the delay itself and negative delays are impossible, it is clear that the delays were not normally distributed. It appears, however, that the log of the ignition delay was more symmetrically distributed. For this reason, in estimating mean ignition delays the log of the ignition delay was used in defining average values.

A further complication in determining mean values of ignition delay arose where ignition was not always successful. If the ignition delay is used as a parameter to represent conditions within the propellant bed, any mean value intended to give a measure of these conditions will be biased in that the average can only be taken under circumstances leading to successful ignition. Interpreting ignition delay in this sense, as a parameter representing conditions in the bed, it is postulated that t_{IG} exists whether or not ignition occurs. Should t_{IG} then exceed a critical value ignition will fail. With t_{IG} seen in this way, experiments in which ignition does not take place may be taken into account in estimating a mean value of ignition time. This has been done here by assuming a log-normal distribution for t^*_{IG} and by using

a cumulative probability plot for $\ln(t^*_{IG})$. Such a plot is shown in figure 4 for experiments with propellant at various distances from the primer. The straight lines represent a best fit to these results assuming a constant standard deviation in $\ln(t^*_{IG})$ for all experimental conditions. From these plots, the mean ignition time $\overline{t^*_{IG}}$ is derived from the intercept of the lines of best fit with the 50% probability level. For all experiments reported here the mean time to ignition has been determined using this technique.

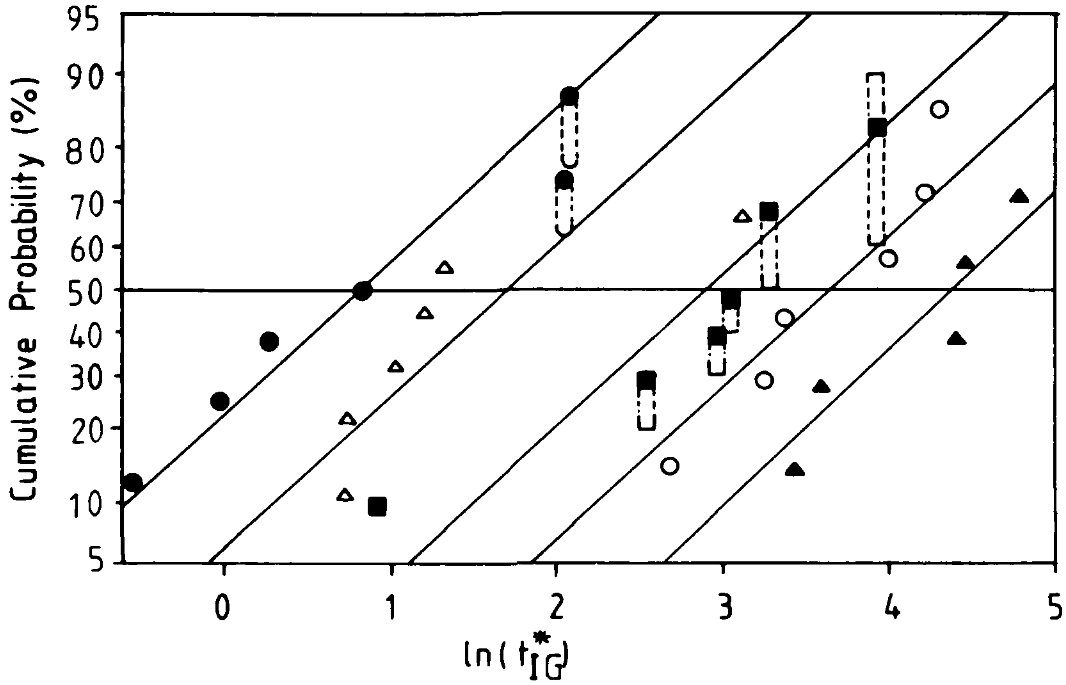

Figure 4. Cumulative probability plot for ignition delay
Symbols relate to experiments at different primer to propellant distances

Other parameters used in examining the experimental results such as the times to detection of the primary pressure rise, maximum slope of the main pressure rise and rise time τ were obtained using the methods outlined previously by Stephenson(ref.2). The emphasis at this stage, however, has been on the ignition delay time due to its sensitivity to experimental conditions.

4. RESULTS AND DISCUSSION

Prior to discussing the results of the experiments in detail, a few remarks will be made on observations during the investigation. Preliminary experiments were conducted using beds containing only inert grains. It was noted that the maximum recorded pressure never exceeded 2 MPa. With 0.355 mg of propellant present, primer maximum pressures were consistently larger. It is evident that the pressure developed by the passage of primer gases is sustained by the propellant, probably as a result of some initial local combustion not leading directly to a self sustaining reaction. Experiments were also undertaken using inert material in both the glazed and unglazed condition. In this case no significant difference between the results with the two differently treated inert grains was observed. Finally, many pressure records showed a disturbance preceding the rise due to the passage of primer

gases. Such an effect is evident in the pressure trace of figure 3. A disturbance of this kind could not be induced by mechanically disturbing the experimental apparatus and is assumed to arise from a local increase in pressure resulting from a disturbance of the bed which propagates faster than the pressure pulse from the primer.

TABLE 1. MEASUREMENTS AT POSITION A

	Primer to propellant distance H (mm)					Overall average
	1	2	3	4	5	
$\overline{(p_1)_{max}}$ [MPa] s	4.89 1.17	5.02 0.76	4.68 1.78	4.10 0.94	3.75 1.63	4.51 1.30
$\overline{(\dot{p}_1)_{max}}$ [GPa/s] s	12.9 3.1	12.9 2.4	12.5 5.5	11.4 2.9	10.2 5.2	12.1 3.8
$\overline{(\dot{P}_1)_{max}/(p_1)_{max}}$ [10^3 s^{-1}] s	2.64 0.06	2.57 0.19	2.63 0.27	2.78 0.24	2.64 0.30	2.65 0.22
τ [ms] s	1.05 0.09	0.98 0.03	1.12 0.06	1.09 0.06	1.15 0.24	1.07 0.12
$\overline{\tau(\dot{p})_{max}}$ [MPa] s	64.2 4.0	60.9 6.7	63.5 6.4	59.9 8.7	56.7 3.2	61.4 5.8
$\overline{\ln(t^*_{IG})}$ [t^*_{IG}-ms] s	0.84	1.72	2.92 -1.102	3.65	4.38	na -1.102
t_{det} [ms] s	0.666 0.040	0.664 0.079	0.683 0.160	0.625 0.284	0.730 0.045	0.672 0.148

TABLE 2. MEASUREMENTS AT POSITION B

	Primer to propellant distance H (mm)					Overall average
	1	2	3	4	5	
$\overline{(p_1)_{max}}$ [MPa] s	3.90 0.80	3.77 0.86	3.10 0.25	3.17 0.82	2.63 0.65	3.26 1.05
$\overline{(\dot{p}_1)_{max}}$ [GPa/s] s	5.18 1.50	4.50 1.65	4.07 1.34	4.18 1.56	3.69 1.48	4.37 1.48
$\overline{(\dot{p}_1)_{max}/(p_1)_{max}}$ [$10^3\ s^{-1}$] s	1.32 0.23	1.28 0.59	1.21 0.42	1.41 0.59	1.37 0.40	1.31 0.43
$\overline{\tau}$ [ms] s	0.79 0.14	0.78 0.16	0.92 0.12	0.93 0.26	1.03 0.06	0.89 0.18
$\overline{\tau(\dot{p})_{max}}$ [MPa] s	59.2 7.3	60.2 6.2	63.2 2.2	58.9 14.0	60.9 12.3	60.5 8.4
$\overline{\ln(t^*_{IG})}$ [t^*_{IG}-ms] s	1.10	1.84	3.00 0.971	3.65	4.31	na 0.971
t_{det} [ms] s	0.895 0.059	1.00 0.30	0.946 0.196	0.825 0.258	1.038 0.180	0.934 0.214

TABLE 3. RELATIVE MEASUREMENTS BETWEEN A AND B

	Primer to propellant distance H (mm)					Overall average
	1	2	3	4	5	
$(p_1)_{max,A}/(p_1)_{max,B}$ s	1.25 0.15	1.38 0.31	1.35 0.35	1.38 0.46	1.49 0.48	1.36 0.34
$(p_1)_{max,A}/(p_1)_{max,B}$ s	2.56 0.56	3.27 1.39	3.34 1.50	3.01 0.96	2.96 0.55	3.03 1.06
$t_{det,A}-t_{det,B}$ [ms] s	0.23 0.05	0.34 0.26	0.26 0.05	0.20 0.12	0.33 0.15	0.27 0.15
$t_{IG,A}-t_{IG,B}$ [ms] s	0.64 0.15	1.15 0.32	0.92 0.28	1.48 0.86	0.44 0.31	0.91 0.43

Tables 1, 2 and 3 show the values of various quantities measured when different thicknesses of inert propellant were placed between the layer of live propellant and the primer. While the maximum primary pressure is consistently less at port B than at port A (closest to the primer), there is little effect on its magnitude as the position of the propellant layer is changed within the limits explored. The fact that the pressure is less at

port B than at port A indicates a decay in the pressure as it travels downstream through the inert bed. This is in contrast to the observation above that it appears to be enhanced in travelling through a propellant layer. Further experiments in beds with varying thicknesses of propellant should clarify this point and enable quantitative assessment of rates of enhancement and decay.

The rise times τ at ports A and B differ but again seem independent of the position of the layer of propellant. It is likely that with different charges of propellant different rise times will be observed and will depend directly on the amount of propellant present. That the rise time at port B is smaller (and the corresponding rate of pressure rise higher) is not surprising. The initial rise in pressure is detected at B somewhat later than at A and it is reasonable that the rate of rise at B will be greater if the final pressure in the chamber is to approach a constant value. Furthermore, as the pressure in the chamber increases, the rate of propagation of pressure disturbances can be expected to increase and this will lead to a steepening of the pressure front as it progresses downstream. This effect, already observed by many authors, will have consequences for the rate of pressure rise on the base of the projectile in a normal round.

Observation of the times to detection at ports A and B indicate that the initial primer pulse travels through the bed with a mean effective speed of 45 ms^{-1}. Stephenson(ref.3) estimates the speed of an intergranular stress wave in an undisturbed bed of AR2206 to be 270 ms^{-1}, which is a considerably higher speed. Consequently any mechanical disturbance initiated by the primer would precede the rise in pressure resulting from the passage of primer gases, and may as indicated above, explain the disturbance in the pressure signals which precede the rise in pressure due to passage of primer gases. Such disturbances could also lead to local propellant grain damage and would further enhance ignition as postulated by Zimmerman(ref.4,5,6). This view also is supported by the observation that primer maximum pressures are greater when propellant is present.

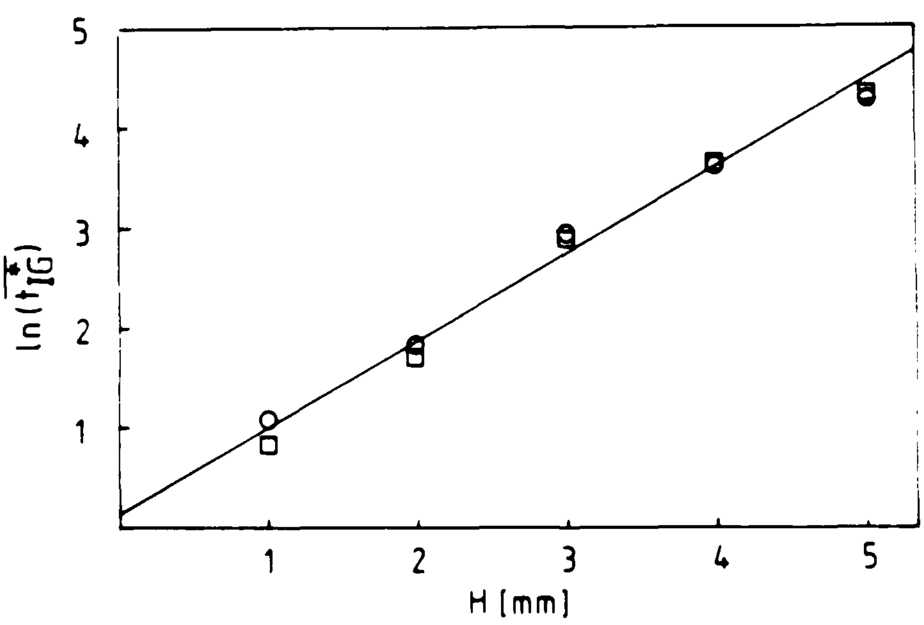

Figure 5. Relationship between mean normalised ignition delay and separation H

The times of ignition for different thicknesses of inert propellant between the primer and the propellant layer are shown in figure 5. Investigation of the effect of this relationship for changes in propellant charge, in chamber geometry and in primer-propellant combination will give insight into ignition behaviour. The inverse of the slope of the $\ln(\overline{t^*_{IG}})$-H curve has the dimension of length and indicates a characteristic depth of penetration of the bed by the primer hot particles and gases. For the primer-propellant combination used in these experiments this characteristic length is 1.2 mm which is of the same order of magnitude as the dimension of the propellant grains. Similar tests under different experimental conditions would indicate the dependence of this penetration depth on propellant size and geometry and on primer composition, leading to quantitative comparison of different primer propellant systems. The absolute value of $\ln(\overline{t^*_{IG}})$, or specifically the intercept of the $\ln(\overline{t^*_{IG}})$-H curve with the $\ln(\overline{t^*_{IG}})$ axis gives a measure of the strength of the primer used. As a further parameter useful in characterising the ignition process, the distance at which half of all experiments fail to produce ignition can be related using the $\ln(\overline{t^*_{IG}})$-H curve, to a critical ignition time.

To examine the nature of the ignition process in absolute rather than relative terms, an increased number of pressure sensors would be required to more fully describe the pressure build-up within the cartridge. It would also be desirable to measure not only the propagation of the pressure fronts but also of the flame fronts and intergranular stress waves. Nonetheless, simpler experiments of the type described above can be successfully used in characterising ignition and comparing different ignition systems. Further work to complete this characterisation will involve the use of different propellant charges and the determination of a "standard" behaviour suitable for quantitative comparisons.

5. CONCLUSION

Preliminary experiments on ignition of layers of propellant in an otherwise inert bed show that the technique can be effectively used to examine the ignition characteristics of different primer-propellant-geometry combinations. It appears that the effectiveness of the primer is enhanced by the propellant itself and further tests with different charge weights of propellant can be used to test this proposition.

The ignition delay time measured in the reported experiments is very sensitive to experimental conditions and should prove useful for this reason in comparative studies. Other parameters which may prove useful in further characterising ignition have been measured and further testing with different primers and propellants will enable determination of their significance in the ignition process.

Further experiments of the type described here will be carried out using various charge weights in the primer and using different propellants in varying quantities to further characterise ignition in small arms. The use of more sensors to measure the development of pressure spatially within the cartridge and to measure the propagation of pressure waves, flame fronts and intergranular stress waves within the granular bed should give even greater insight into the ignition and combustion mechanisms involved.

NOMENCLATURE

A	as subscript or parameter refers to measurement at pressure port A closest to percussion cap
B	as subscript or parameter refers to measurement at pressure port B closest to tip of modified cartridge
H	thickness of inert material between base and propellant
p	total pressure
p_{max}	maximum pressure
$\dot{p}$	time derivative of pressure
$\dot{p}_{max}$	maximum value of time derivative of pressure
p_1	primary pressure due to the primer(ref.2)
$(p_1)_{max}$	maximum of p_1
$\dot{p}_1$	time derivative of p_1
$(\dot{p}_1)_{max}$	maximum of $\dot{p}_1$
s	sample standard deviation
t^*_{IG}	ignition delay
t_{IG}	normalised ignition delay
t_{det}	time from firing to detection of first pressure rise
τ	rise time(ref.2)
$(\overline{})$	overbar denotes average of quantity over a series of tests

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APPENDIX I

CALCULATION OF THE TIME DERIVATIVE

To calculate numerically the derivative of a function f(t), the function is approximated by fitting a quadratic to n points on each side of the point at which the derivative is to be found (2n+1 points in all). This quadratic is then analytically differentiated to yield an expression g(t) for the derivative given by

$$g(t) = \frac{3}{n(n+1)(2n+1)\Delta} \sum_{k=-n}^{n} k\, f(t+k\Delta) \qquad (I.1)$$

where Δ is the time interval between measured points.

The amplitude ratios of estimated to actual derivative for harmonic functions A sin(wt+ϕ) and exponentials A $e^{t/\tau}$ are given below

$$\underline{\text{Harmonic}} \quad \frac{g(t)}{f'(t)} = \frac{3}{n(n+1)(2n+1)\Delta\omega} \, \frac{(n+1)\sin n\omega\Delta - n\sin(n+1)\omega\Delta}{1-\cos\omega\Delta} \qquad (I.2)$$

$$\underline{\text{Exponential}} \quad \frac{g(t)}{f'(t)} = \frac{3}{n(n=1)(2n=1)\Delta/\tau} \, \frac{n\sinh(n+1)\frac{\Delta}{\tau} - (n+1)\sinh\frac{n\Delta}{\tau}}{\cosh\frac{\Delta}{\tau} - 1} \qquad (I.3)$$

These examples show that as far as errors are concerned ω behaves like $1/\tau$. However, in the case of exponential curves the estimate for the derivative is understandably larger while for harmonic signals the estimate is proportionally less than the true value.

To ensure accurate differentiation in the experiments reported, n has been chosen to give a 3 dB cutoff (based on derivative amplitude) for frequencies exceeding 1.6 kHz($\omega = 10^4\ s^{-1}$, $\tau = 0.1$ ms). This corresponds to a 0.5% error in the maximum frequencies of $\omega = 10^3\ s^{-1}$ of interest in the experiments. Table I.1 gives the typical number of points used for the different sampling rates employed in the experiments.

TABLE I.1 VALUES USED FOR DERIVATIVE

Δ (ms)	n for $\left\|\frac{g(t)}{f'(t)}\right\| = 0.5$ at $\omega = 10^4\ s^{-1}$	$\left\|\frac{g(t)}{f'(t)}\right\|$ at $\omega = 10^3\ s^{-1}$; $\tau = 1$ ms
0.005	49	0.994
0.01	24	0.994
0.025	9	0.994
0.05	4	0.995

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Security classification of this page: UNCLASSIFIED

1 DOCUMENT NUMBERS

AR Number:	AR-004-617
Series Number:	WSRL-0447-TM
Other Numbers:	

2 SECURITY CLASSIFICATION

a. Complete Document:	Unclassified
b. Title in Isolation:	Unclassified
c. Summary in Isolation:	Unclassified

3 TITLE

A TECHNIQUE FOR INVESTIGATION OF IGNITION PHENOMENA IN SMALL ARMS AMMUNITION

4 PERSONAL AUTHOR(S)

S.E. Stephenson

5 DOCUMENT DATE

May 1986

6

6.1 TOTAL NUMBER OF PAGES: 13

6.2 NUMBER OF REFERENCES: 6

7 7.1 CORPORATE AUTHOR(S)

Weapons Systems Research Laboratory

7.2 DOCUMENT SERIES AND NUMBER

Weapons Systems Research Laboratory 0447-TM

8 REFERENCE NUMBERS

a. Task: DST 83/121

b. Sponsoring Agency:

9 COST CODE

330212

10 IMPRINT (Publishing organisation)

Defence Research Centre Salisbury

11 COMPUTER PROGRAM(S) (Title(s) and language(s))

12 RELEASE LIMITATIONS (of the document)

Approved for Public Release

Security classification of this page: UNCLASSIFIED

Security classification of this page: UNCLASSIFIED

13 ANNOUNCEMENT LIMITATIONS (of the information on these pages):

No limitation

14 DESCRIPTORS:

a. EJC Thesaurus Terms	Primers (explosives) Initiators (explosives Caps (explosives) Ignition
b. Non-Thesaurus Terms	Primer caps

15 COSATI CODES:

19010

16 SUMMARY OR ABSTRACT:
(if this is security classified, the announcement of this report will be similarly classified)

Results are reported of experiments in which layers of propellant, sandwiched between layers of inert material in a modified 7.62 mm cartridge were ignited using standard Boxer percussion caps. These experiments yielded measurements of the penetration of the bed by the primer gases and hot particles and the corresponding effects on ignition. The technique is shown to be useful in characterising ignition and further experiments of a similar nature are proposed.

Security classification of this page: UNCLASSIFIED

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Technical Reports	:	records of scientific and technical work of a permanent value intended for other scientists and technologists working in the field.
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